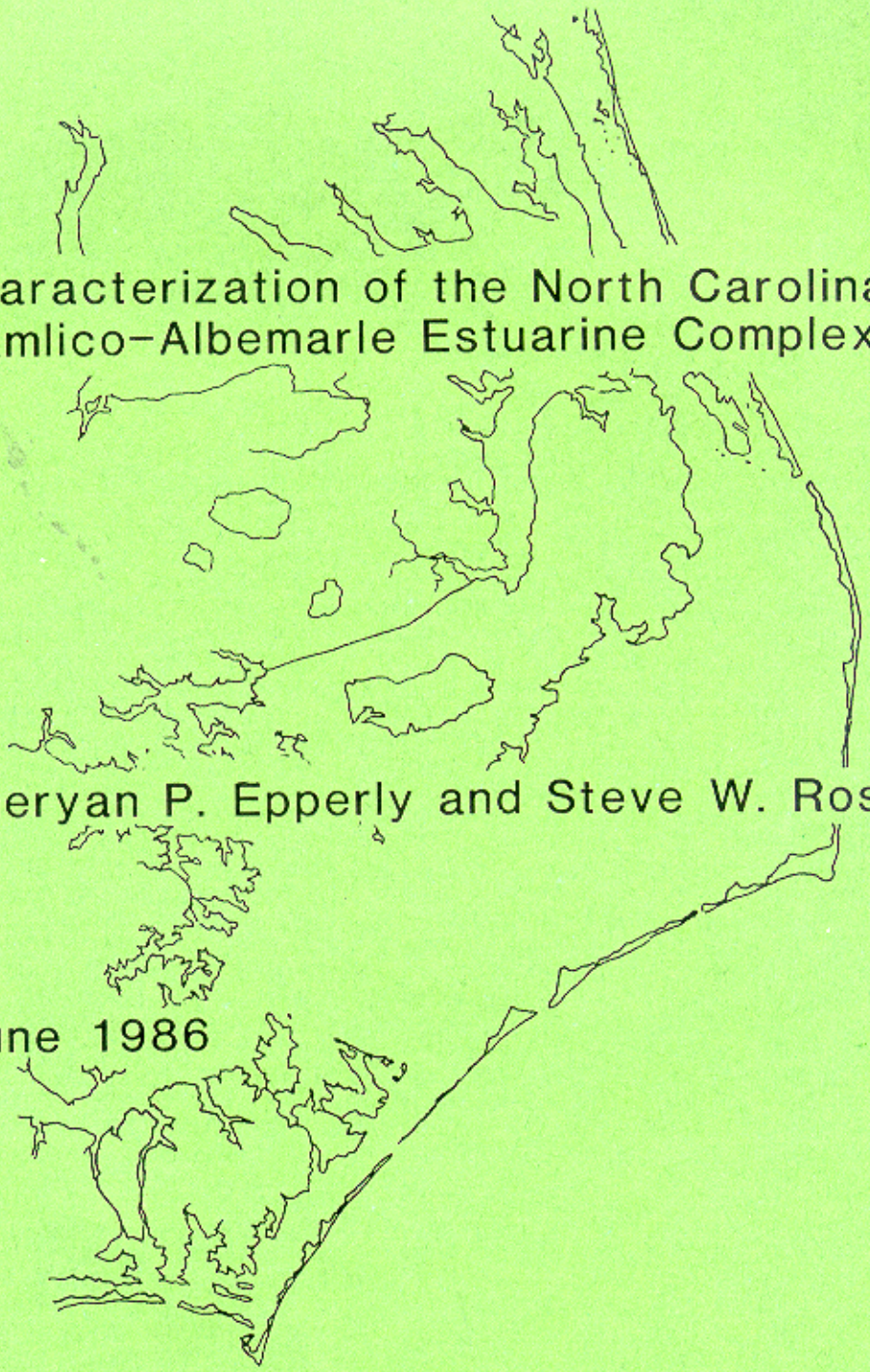
NOAA Technical Memorandum NMFS-SEFC-175

Characterization of the North Carolina Pamlico-Albemarle Estuarine Complex



Sheryan P. Epperly and Steve W. Ross

June 1986

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmosperic Administration
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ERRATA

for

"Characterization of the North Carolina Pamlico-Albemarle Estuarine Complex" by Sheryan P. Epperly and Steve W. Ross. June 1986. (NOAA Technical Memorandum NMFS_SEFC-175)

Please replace Table 1 in text with Table 1 below:

Table 1. Characteristics of some United States estuarine systems (Gross 1972; Roelofs and Bumpus 1953; B.J. Copeland pers. commun.).

	Estuary area km^2 (mi^2)	Estuary volume $m^3 x10^8$ ($ft^3 x10^9$)
Chesapeake Bay	12,930 (4,992)	766 (2,705)
Pamlico-Albemarle Sound	7,101 (2,742)	239 (844)
Long Island Sound	3,180 (1,228)	620 (2,189)
Puget Sound	2,640 (1,019)	1,850 (6,532)
San Francisco Bay	1,190 (459)	62 (219)

revised 4/6/87

ERRATA

for

"Characterization of the North Carolina Pamlico-Albemarle Estuarine Complex" by Sheryan P. Epperly and Steve W. Ross. June 1986. (NOAA Technical Memorandum NMFS-SEFC-175)

Please replace Table 2 in text with Table 2 below:

Table 2. Comparison of the Albemarle and Pamlico sound areas (Roelofs and Bumpus 1953; Giese et al. 1979; N.C. Div. Mar. Fish. unpubl. data; B. J. Copeland pers. commun.). The Albemarle Sound area includes Currituck and Croatan sounds and the Pamlico Sound area includes Core and Roanoke sounds. Tributaries are included. Landings are based on 1979-1986 data.

	Albemarle	Pamlico
Area (km^2)	2,415	4,686
(mi^2)	932	1,809
Watershed (km^2)	47,552	32,427
(mi^2)	18,360	12,520
Percent area of state inshore total	28	55
Salinity	low	moderate to high
Fisheries	anadromous and fresh	marine
Percent catch of state total, excluding industrial fish landings	12.6	45.2
Percent value of state total, excluding industrial fish landings	5.2	41.7

revised 4/6/87

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June 1986

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
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Anthony J. Calio, Administrator
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Characterization of the North Carolina Pamlico-Albemarle Estuarine Complex

Sheryan P. Epperly and Steve W. Ross

ABSTRACT

The Pamlico-Albemarle estuarine complex is one of the largest and most productive aquatic systems in North America. Near the inlets salinities are relatively high and hydrography is dominated by lunar tidal flow. With increasing distance from the inlets, salinities decrease and hydrography is dominated by wind-generated flow in Pamlico Sound and by riverine flow in Albemarle Sound. Nursery area utilization by nekton can be divided into two types of areas, based on salinity. The low salinity Currituck and Albemarle sounds, and upstream tributaries of Pamlico Sound are used most intensively by anadromous and primary freshwater species. The fauna of higher salinity Pamlico and Core sound nursery areas are dominated by young of marine species spawned offshore during the winter or spring or that are spawned inshore during the summer. Economically important sessile shellfish are restricted to the higher salinity regions of the complex. The estuarine commercial and recreational fisheries in the area are dependent on the same species groups using the nursery areas.

Development within the watershed of the Pamlico-Albemarle complex has negatively impacted the estuary and the resultant environmental stress is likely to increase. Effective mitigation of the impacts will require the involvement of North Carolina, Virginia and the Federal government; however, much basic ecological research still is needed to define the trophic structure and patterns of utilization within the estuarine complex and to identify sources of environmental degradation.

INTRODUCTION

The importance of shallow estuarine and lagoonal habitats to fish production is well established. Over half of the total United States commercial fisheries catch is composed of estuarine species, and this proportion is generally higher in the southeastern United States where, for example, about 90% of the North Carolina commercial landings are composed of estuarine-dependent species (Ross and Epperly in press). The largest southeastern estuarine system is the Pamlico-Albemarle complex, located in northeastern North Carolina. This lagoonal system is the third largest estuarine complex in North America and the second largest in area in the United States (Table 1).

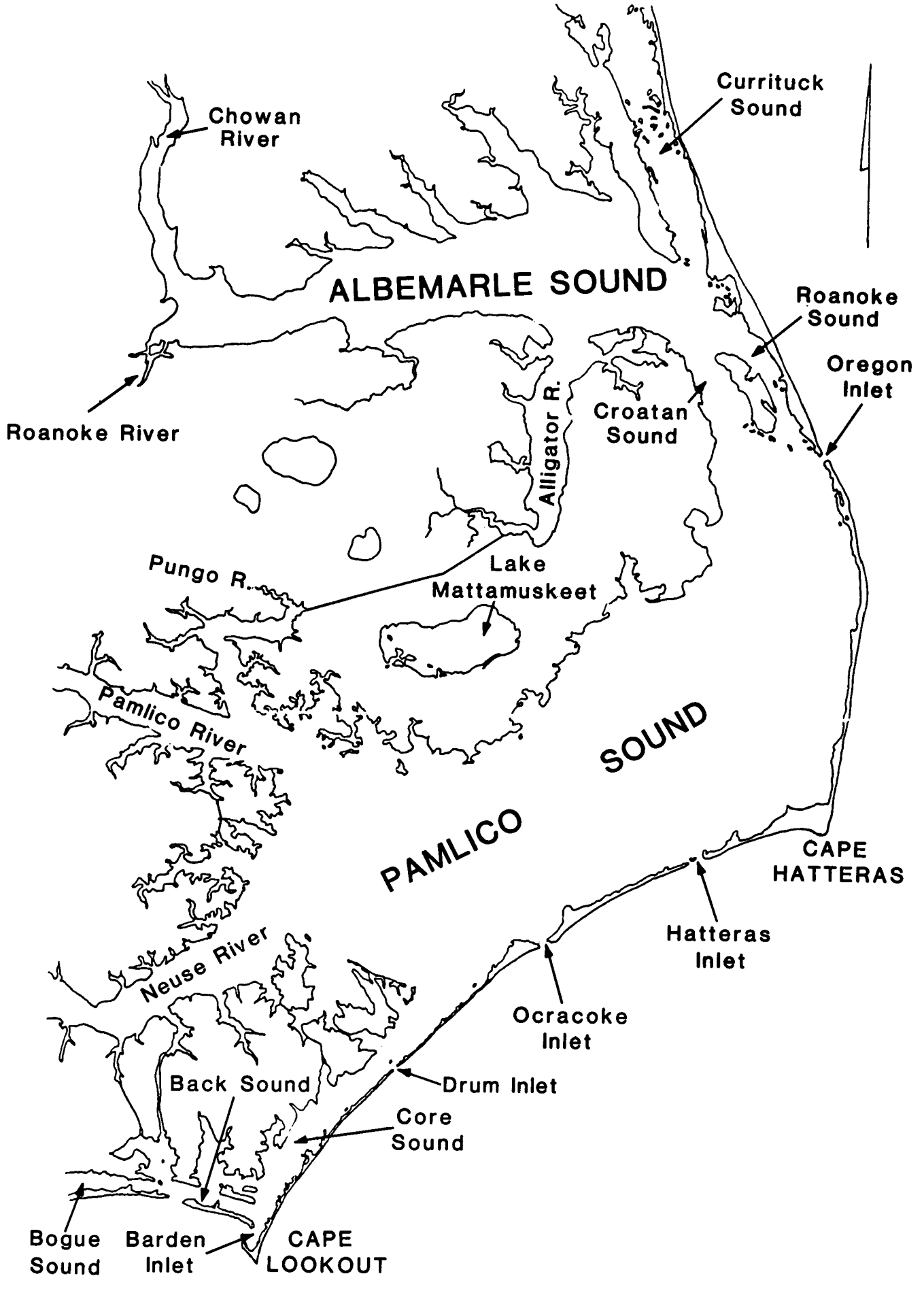
On 16 April 1986 the U.S. Environmental Protection Agency (EPA) announced initial funding of a major long-term project to study water quality in the Pamlico-Albemarle Sound estuarine complex as part of their National Estuarine Program. In light of the proposed attention to the Pamlico and Albemarle sounds and since there are no data summaries covering the entire area, we have attempted to provide a brief initial synthesis of the existing data. We did not include all references or data known for this area, but used selected publications and reports and personal observations. Much of the data available for this estuarine complex have not been analysed or are in the form of unpublished reports of several government agencies and universities.

Throughout this report we concentrate primarily on aspects relevant to commercial and recreational fisheries.

Table 1. Characteristics of some United States estuarine systems (Gross 1972; Giese et al. 1979).

	Estuary area km^2 (mi^2)	Estuary volume $m^3 x10^8$ ($ft^3 x10^9$)
Chesapeake Bay	12,930 (4,992)	766 (2,705)
Pamlico-Albemarle Sound	6,630 (2,560)	326 (1,151)
Long Island Sound	3,180 (1,228)	620 (2,189)
Puget Sound	2,640 (1,019)	1,850 (6,532)
San Francisco Bay	1,190 (459)	62 (219)

Figure 1. The North Carolina Pamlico-Albemarle estuarine complex.


Currituck Sound
Chowan River
ALBEMARLE SOUND
Roanoke Sound
Oregon Inlet
Roanoke River
Alligator R.
Croatan Sound
Pungo R.
Lake Mattamuskeet
Pamlico River
PAMLICO SOUND
CAPE HATTERAS
Hatteras Inlet
Neuse River
Ocracoke Inlet
Back Sound
Drum Inlet
Core Sound
Bogue Sound
Barden Inlet
CAPE LOOKOUT

The vast majority of information is on the fisheries resources, but considering the size and importance of the Pamlico-Albemarle area, the scarcity of studies on non-fisheries topics is surprising. In a literature review of studies on non-commercial invertebrates in Pamlico Sound, Stearns et al. (in press) found no comprehensive ecological studies that included such aspects as primary productivity, trophodynamics, energy budgets, nutrients, or benthos and plankton dynamics from any of the primary, shallow fishery nursery areas. They reported that some of these topics were scattered among reports mainly from the deeper areas of the Pamlico and Neuse rivers. It is apparent that there are many data gaps that must be filled before an accurate ecological understanding of the Pamlico-Albemarle area can be achieved. Miller et al. (1984) and Deegan and Day (1984) outlined some specific questions to be addressed.

PHYSICAL DESCRIPTION

The Pamlico-Albemarle complex is actually a coastal lagoon separated from the ocean by barrier islands breached by the small and shifting Oregon, Hatteras, Ocracoke, Drum and Barden inlets (Figure 1). This large and diverse complex is composed of six sounds: Currituck, Albemarle, Croatan, Roanoke, Pamlico, and Core (Figure 1).

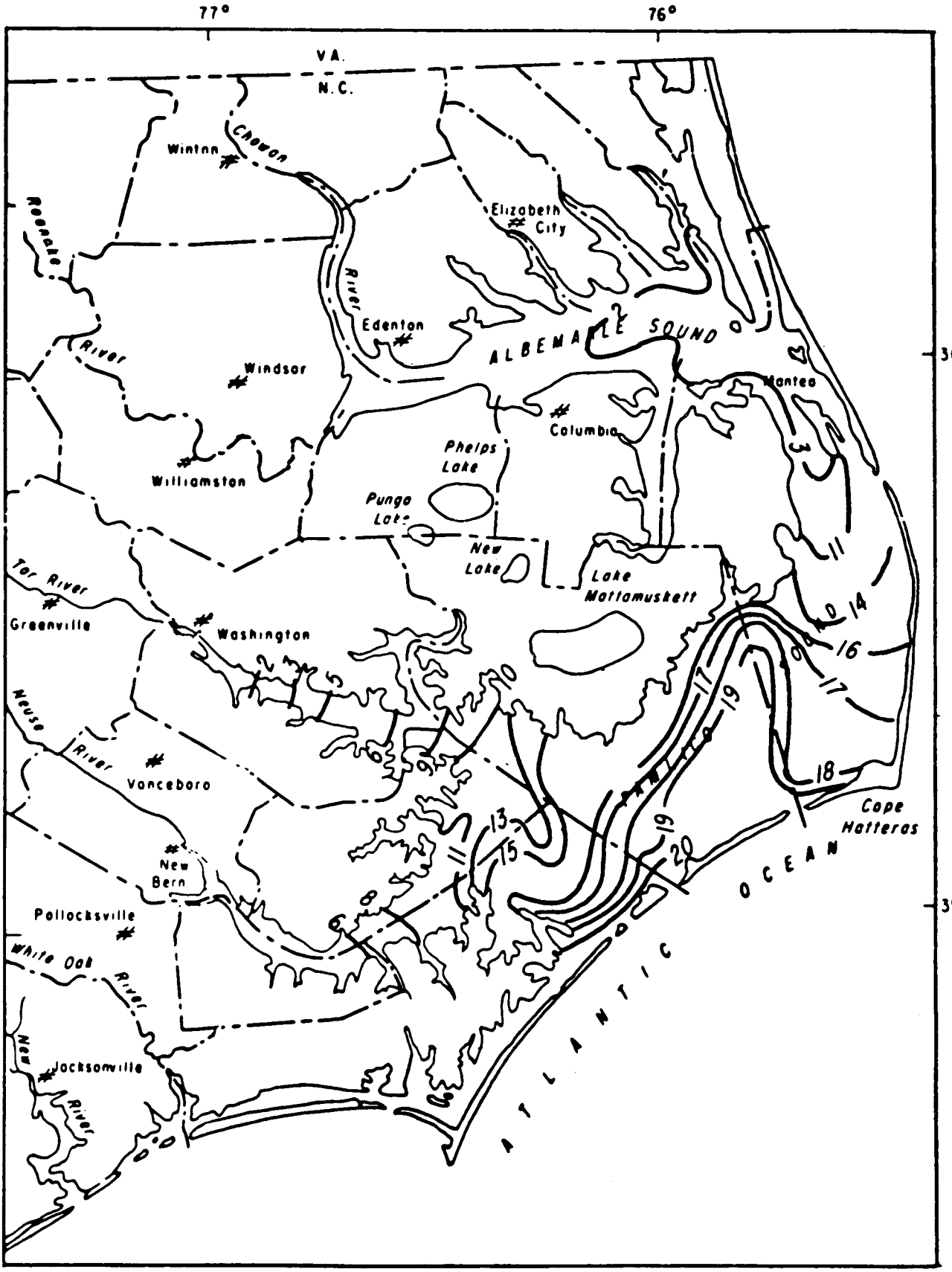
The estimated drainage area of the entire complex is 79,979 km^2 (30,880 mi^2) (Giese et al. 1979). The Neuse and Pamlico rivers, originating in the Piedmont area, discharge directly into western Pamlico Sound and drain nearly 26,000

km^2 (10,000 mi^2). Average discharge rates for the two rivers are 173 m^3/s (6,000 ft^3/s) and 154 m^3/s (5,400 ft^3/s), respectively. Chowan and Roanoke rivers, originating in the Piedmont and Allegheny Mountains of Virginia, drain 37,837 km^2 (14,609 mi^2) and empty into western Albemarle Sound. Average discharge rates are 130 m^3/s (4,600 ft^3/s) and 252 m^3/s (8,900 ft^3/s), respectively. In addition, there are many short, wide streams and embayments collecting overland runoff from the extensive pocosins characteristic of eastern North Carolina, including a 4232 km^2 (1,634 mi^2) peninsula separating Pamlico and Albemarle sounds.

Salinities of the open waters vary seasonally but range from polyhaline (18-30 $^{o}/oo$) in Core Sound and eastern Pamlico Sound to oligohaline (0.5-5.0 $^{o}/oo$) in Albemarle Sound (Figure 2) (Giese et al. 1979). On the average, April is the month of lowest salinities and December is the month of highest salinities. Within a sound, salinities typically decrease with increasing distance from the inlets except where alterations such as the Atlantic Intracoastal Waterway facilitate reversals (e.g., upper Alligator River is frequently saltier than the mouth).

Pamlico and Albemarle sounds are the largest components of the complex, but differ significantly in their physiography and hydrography (Table 2) (Giese et al. 1979). The waters of Pamlico Sound are shallow (mean depth 16 ft (5 m)), saline and dominated by lunar tidal (eastern sound) and wind-generated flow (western sound). In contrast, Albemarle

Figure 2. Average April surface salinity profile of major North Carolina estuaries by contours (-19-). Compiled by Giese et al. (1979).



AVERAGE SURFACE SALINITY OF PAMLICO SOUND, N.C. AREA WATERS BY CONTOURS (—19—) (April) .

Table 2. Comparison of the Albemarle and Pamlico sound areas (Giese et al. 1979; N.C. Div. Mar. Fish., unpubl. data). The Albemarle Sound area includes Currituck and Croatan sounds and the Pamlico Sound area includes Core and Roanoke sounds. Tributaries are included. Landings are based on 1968-1985 data.

	Albemarle	Pamlico
Area (km^2)	1,243	5,335
(mi^2)	480	2,060
Watershed (km^2)	47,552	32,427
(mi^2)	18,360	12,520
Percent area of state inshore total	15	62
Salinity	low	moderate to high
Fisheries	anadromous and fresh	marine
Percent catch of state total, excluding industrial fish landings	11.9	46.0
Percent value of state total, excluding industrial fish landings	5.2	41.3

Sound is slightly deeper (mean depth 17 ft), much smaller in volume (Table 2), and outflow is relatively large ($490 m^3/s$ or $17,300 ft^3/s$), creating sufficient flow to effectively block saline waters entering through Oregon Inlet. Because of the large distance to the nearest inlet, tidal amplitude is dampened and the hydrography of Albemarle Sound is overshadowed by wind tides and riverine flow. Roanoke and Croatan sounds are transitional areas between Pamlico and Albemarle sounds. Core Sound, a shallow water body, experiences little freshwater inflow and due to its close proximity to the ocean, hydrography is dominated by lunar tidal flow.

The diverse physiographic and hydrologic regimes help create diverse estuarine habitats. Seagrasses (mostly Zostera marina) account for much of the available shallow habitat behind the Outer Banks (Carraway and Priddy 1983). Other submerged vegetation is found in the embayments along the southern perimeter of the Pamlico-Albemarle Peninsula (J. Hawkins, N.C. Div. Mar. Fish., pers. commun.) and in the Pamlico River (Davis and Brinson 1976). The open waters of the sounds generally provide sandy substrates except in the deeper central basins and near the river mouths where finer sediment fractions accumulate (Folger 1972). Substrates in the upstream coastal sections of the rivers, the embayments, and tributary creeks are generally coarse silt and clay with a considerable detrital component (Ross and Epperly in press). Shorelines grade from marsh grasses (Spartina and Juncus) around Core, Pamlico, Roanoke, and Croatan sounds to

upland and swamp forests and banks and bluffs upstream and around Albemarle Sound. Besides substrate, major factors influencing the biota of the estuarine complex are salinity, depth, and proximity to sources of recruiting larvae.

NURSERY AREA USAGE BY MOTILE MARINE ORGANISMS (NEKTON)

The Pamlico-Albemarle system and their major tributaries can be divided into two types of usage areas, based on salinity. Low salinity areas, generally $\leq$ 5-6^{o}/oo, include most of Albemarle and Currituck sounds, their tributaries, and the upper reaches of the Pamlico, Tar, Pungo, Bay, Neuse and Trent rivers. Freshwater and anadromous fishes dominate the nekton here, although at the upper salinity end, these areas may be inundated at certain times by some juvenile and adult marine species. Areas with greater salinity are usually the major province of seasonally abundant marine species, and such areas include Pamlico, Core, Roanoke, and Croatan sounds and the lower reaches of their tributaries. Usage of habitat by juvenile nekton species is discussed separately for the two areas.

Low Salinity Areas

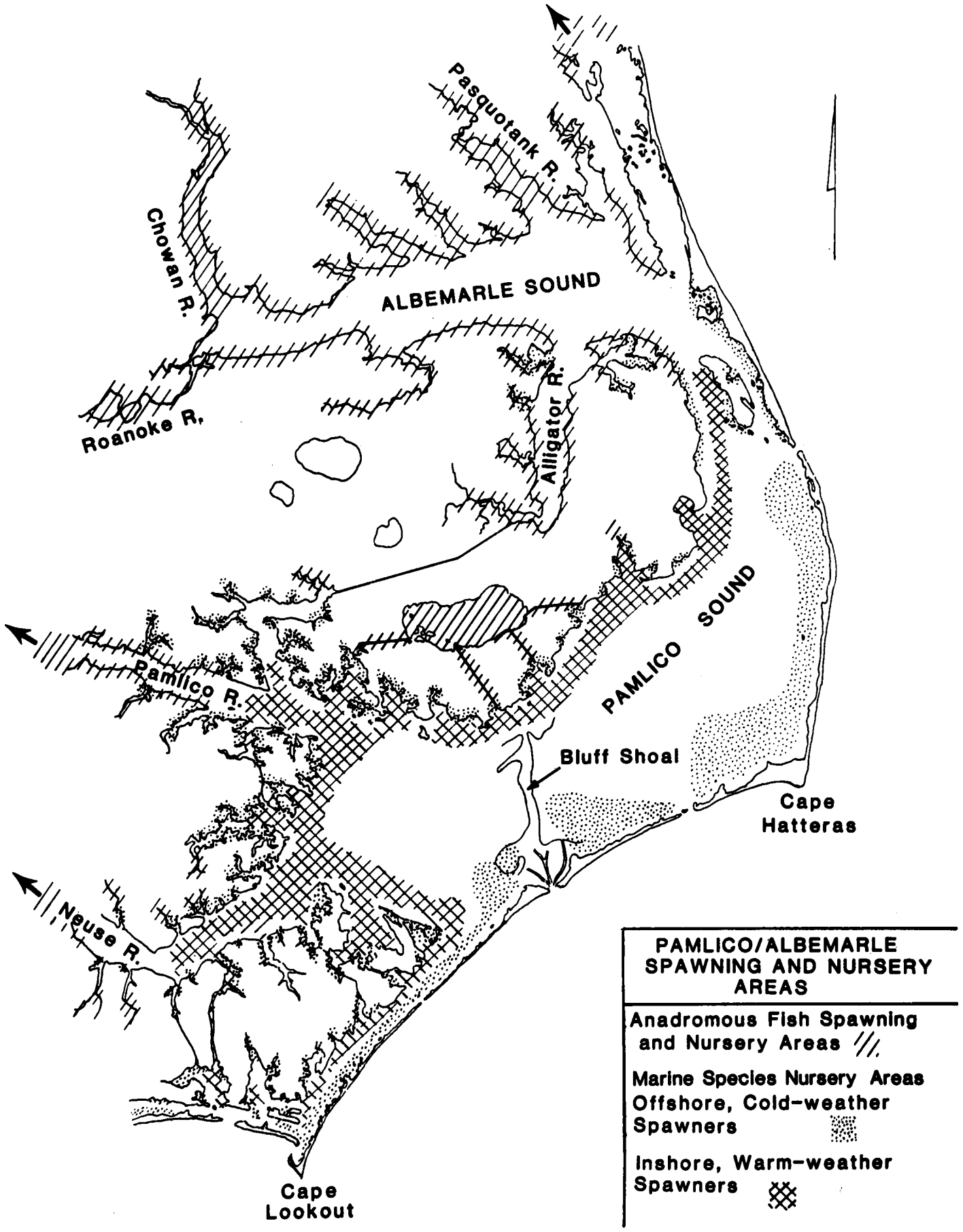
The Albemarle Sound complex is one of the largest coastal bodies of freshwater in the United States and among all of North Carolina's low salinity areas, it is of prime importance in the production of anadromous fishes. Adult herrings, as well as striped bass and Atlantic sturgeon, begin to enter the estuary in late winter and make their way

to freshwater spawning areas in the major rivers and creeks (Street and Pate 1975; Johnson et al. 1981) (Figure 3). After spawning, which peaks during March-May, most of the adults make their way back to sea. The larvae and juveniles move downstream from spawning sites and use mostly shallow, protected areas of Albemarle Sound (Figure 3) from spring through fall (Street and Pate 1975; Johnson et al. 1981). By late fall the juveniles begin to migrate to the ocean. These usage patterns are similar for anadromous species in upper areas of most other major rivers of the Pamlico Sound drainage (Marshall 1976; Hawkins 1980). One exception to the above is that the Pamlico-Albemarle system contains a resident population of striped bass, whose adults move to upriver areas to spawn (as do the non-resident population). This resident population contributes little to the ocean migratory stock (Hassler et al. 1981).

Although anadromous fishes make use of nearly all of the low salinity and freshwater areas at various times, two other major groups use the area in more restricted ways. One group is transient and composed of juveniles and some adults of marine, offshore and nearshore spawners (Atlantic croaker, spot, Atlantic menhaden, southern flounder, and blue crab). They utilize shallow, lower reaches in the 3-8^{o}/oo salinity range and frequently enter freshwater (Epperly 1984). They also occur most abundantly during spring and summer as described in more detail below.

Another group, composed of resident species, carries out all life history phases in the low salinity or

Figure 3. General depiction of major nekton nursery and anadromous fish spawning areas in the Pamlico-Albemarle complex for economically important species (N.C. Div. Mar. Fish., unpubl. data). The nursery areas for warm-weather spawned fish are mainly for weakfish and silver perch. Anadromous nursery and spawning areas are combined, but spawning areas are mostly upriver while nurseries are mostly downriver.


Pasquotank R.
Chowan R.
ALBEMARLE SOUND
Roanoke R.
Alligator R.
Pamlico R.
PAMLICO SOUND
Bluff Shoal
Cape Hatteras
Neuse R.
Cape Lookout
PAMLICO/ALBEMARLE SPAWNING AND NURSERY AREAS
Anadromous Fish Spawning and Nursery Areas
Marine Species Nursery Areas
Offshore, Cold-weather Spawners
Inshore, Warm-weather Spawners

freshwater areas, displaying only localized movements. Although some marine species such as bay anchovy are in this group, most are of freshwater origins and include the white perch, yellow perch, catfishes, sunfishes, and minnows (Keefe and Harriss 1981; Copeland et al. 1983; Epperly 1984). White perch and white catfish are particularly prevalent in this group, spawn in the spring, and are fished heavily (Keefe and Harriss 1981). Both species (and channel catfish) use nearly the entire Chowan River (Keefe and Harriss 1981) and other areas as nursery grounds, but tend to occupy deeper areas during winter (Hester and Copeland 1975). The catadromous American eel is another important fish of the area.

High Salinity Areas

Nearly all shallow ($\leq$ 1.5 m), muddy creeks and bays $\geq$ 8^{o}/oo salinity serve as important nurseries for juvenile nekton, particularily for marine species. Although many of these areas are protected from disturbance (e.g., N.C. Dep. Nat. Resour. Community Dev. 1986a), the protected area is a small percentage of the overall estuary. Additional nursery habitat is also provided by various submerged seagrasses, especially in eastern Pamlico Sound and Core Sound. Carraway and Priddy (1983) mapped 78.7 km^2 (19,458 acres) of grass beds in Bogue and Core sounds.

The fauna of these areas is dominated by young of offshore winter and spring spawners. The post-larvae of spot, Atlantic croaker, southern flounder, brown shrimp,

striped mullet, and Atlantic menhaden occupy the shallow nurseries of Pamlico Sound and tributaries (Figure 3) during March-June. Atlantic croaker and menhaden tend toward the lower salinity creeks, while spot, brown shrimp, striped mullet, and southern flounder are more cosmopolitan or tend toward higher salinity (Ross and Epperly in press). Other offshore, cold weather spawned fishes that are more restricted to occupying only the higher salinity nurseries of Core Sound or eastern Pamlico Sound are gag, pinfish, pigfish, gulf flounder, and summer flounder (Ross and Epperly in press). With the exception of summer flounder, which seems to prefer deeper waters (Powell and Schwartz 1977), these young fishes are most abundant in the protected, shallow creeks and grass beds. Hypothetically, they respond positively to these areas because of high food availability and low predation. Unlike the freshwater areas, these habitats have very few resident species, and those that do reside here never reach large sizes (e.g., gobies, anchovies, pipefishes, grass shrimp, and hogchoker). Some animals slowly leave the shallow nursery areas throughout the summer and most have left by late fall (Epperly 1984). They migrate either to the ocean or to deeper estuarine habitats to overwinter (N.C. Div. Mar. Fish., unpubl. data).

Another group of animals utilizing these mesohaline (5-18^{o}/oo) and polyhaline areas are summer spawners. All of the warm weather spawners whose young use estuaries spawn within the sounds or in nearshore waters. This contrasts

sharply with winter spawners of estuarine dependent species, all of which spawn some distance offshore (Miller et al. 1984). Many warm weather spawners (e.g., weakfish (gray trout), spotted seatrout, red drum, silver perch, and blue crab) apparently spawn in eastern Pamlico Sound or just outside the inlets. Young weakfish and silver perch tend to occupy deeper waters of the bays and lower rivers (Figure 3) (Ross and Epperly in press). Young blue crabs and pink shrimp are usually most abundant in shallow areas (grass beds or muddy, detritus filled creeks). Patterns of nursery usage are less clear for red drum and spotted seatrout, but they are often common in shallow, moderate to higher salinity areas with substrates of grass or mud (Mercer 1984 a, b).

These broad area utilization patterns indicate that shallow, usually vegetated or muddy, protected, detritus filled areas, are the major habitats occupied as nurseries. Overlaying these patterns, Pamlico Sound is divided physically and biologically by Bluff Shoal into two basins (Figure 3). Both nursery area usage patterns and adult fish patterns (as reflected by commercial fisheries) are different east and west of this shoal (Epperly 1984; Ross and Epperly in press). Overall, the most productive of the shallow habitats for major marine species are those on the periphery of Pamlico Sound (in this context all of Core Sound), and secondary or tertiary productivity declines with increasing distance upstream from the periphery of the sound. Decreasing salinities as well as increasing distance

from larval sources probably influence this decline (Ross and Epperly in press).

FISHERIES BASED ON MOTILE MARINE ORGANISMS (NEKTON)

Much more data are available on the inshore commercial fisheries in North Carolina than for the recreational fisheries. Accurate landings estimates for inshore recreational fisheries are unavailable for the area. In general, the recreational fisheries often mirror the commercial fisheries in terms of areas used, species caught, gears, and seasons, except that recreational fishermen are more restricted, using smaller gear and vessels and usually fishing closer to shore. Nearly one-half of the commercial vessel licenses sold in North Carolina were to persons listing themselves as fishing for pleasure; because of the type of gears they were using, they were required to obtain a commercial vessel license (N.C. Div. Mar. Fish., unpubl. data). One major gear that is almost exclusively used recreationally within the sounds and rivers is hook and line. Likewise, the long haul seine is exclusively used as commercial gear. Which fishery, recreational or commercial, removes the most biomass is unknown at this time, but both are valuable to the economy of eastern North Carolina. In 1978 they were estimated to be worth over $325 million to the coastal economy (Street and McClees 1981).

Total fisheries landings data are generally inadequate for determining the status of a fishery or the reasons for changes in fishery yields. Without data on fishing effort,

age-size composition, species composition, cause and effect physical-chemical-biological relationships, and many other factors, the data of Figure 4 are difficult to interpret. In addition, much of the data on fishery production in these waters come from commercial fishery samling. These data are useful for rough comparisons between major fishing areas which are described in more detail below. Long-term fishery-independent surveys with a strong directed purpose are needed to adequately assess the mechanisms which control the Pamlico-Albemarle complex fishery production.

Commercial fisheries in the Albemarle Sound area have traditionally concentrated on the spring runs of anadromous species, especially alewife and blueback herring (together called river herring) (Table 3) and account for the majority of anadromous fish landings in the state (Street and Johnson 1982). Most of tne variability in total landings (Figure 4) is produced by fluctuations in river herring (Figure 5). Decline in landings from 1969 through the early 1980's was attributed to poor water quality and utilization problems (e.g. overfishing of river herring on the high seas) (Street and Johnson 1982; Copeland et al. 1983). The environmental problems still occur in the Albemarle Sound area, but catches have increased recently (Figure 4). Despite problems with interpreting landings data, there are changes in water quality that seem to relate to fish diseases and lack of spawning success in certain species. More stable fisheries for resident species (white catfish, channel catfish, and white perch) exist throughout most of the year

Table 3. Major commercial species by area with approximate percent composition of area total, 1972-1985 (N.C. Div. Mar. Fish., unpubl. data). The Pamlico Sound area includes Core, Croatan, and Roanoke sounds and the Albemarle Sound area includes Currituck Sound. Tributaries are included. All values exclude industrial fish landings.

	Percent
Pamlico Sound Area	
blue crab	40-70
Atlantic croaker	2-20
spot	2-12
shrimp (3 species)	5-15
weakfish	1- 8
flounder (3 species)	2- 6
clams	1- 3
bluefish	<1- 2
oyster	<1- 2
Albemarle Sound Area	
river herring (2 species)	50-70
blue crab	7-20
catfish (2 species)	6-15
striped bass	2- 6
white perch	1- 4
gizzard shad	<1-10
Atlantic croaker	<1- 3
American eel	<1- 3
southern flounder	<1- 2

Figure 4. North Carolina commercial fishery landings data, 1970-1985, for Pamlico and Albemarle sounds (N.C. Div. Mar. Fish., unpubl. data). The Pamlico Sound area includes Core and Roanoke sounds. The Albemarle Sound area includes Currituck and Croatan sounds. Tributaries of the areas are included. Atlantic menhaden landings cannot be separated by water body, and are thus not included.

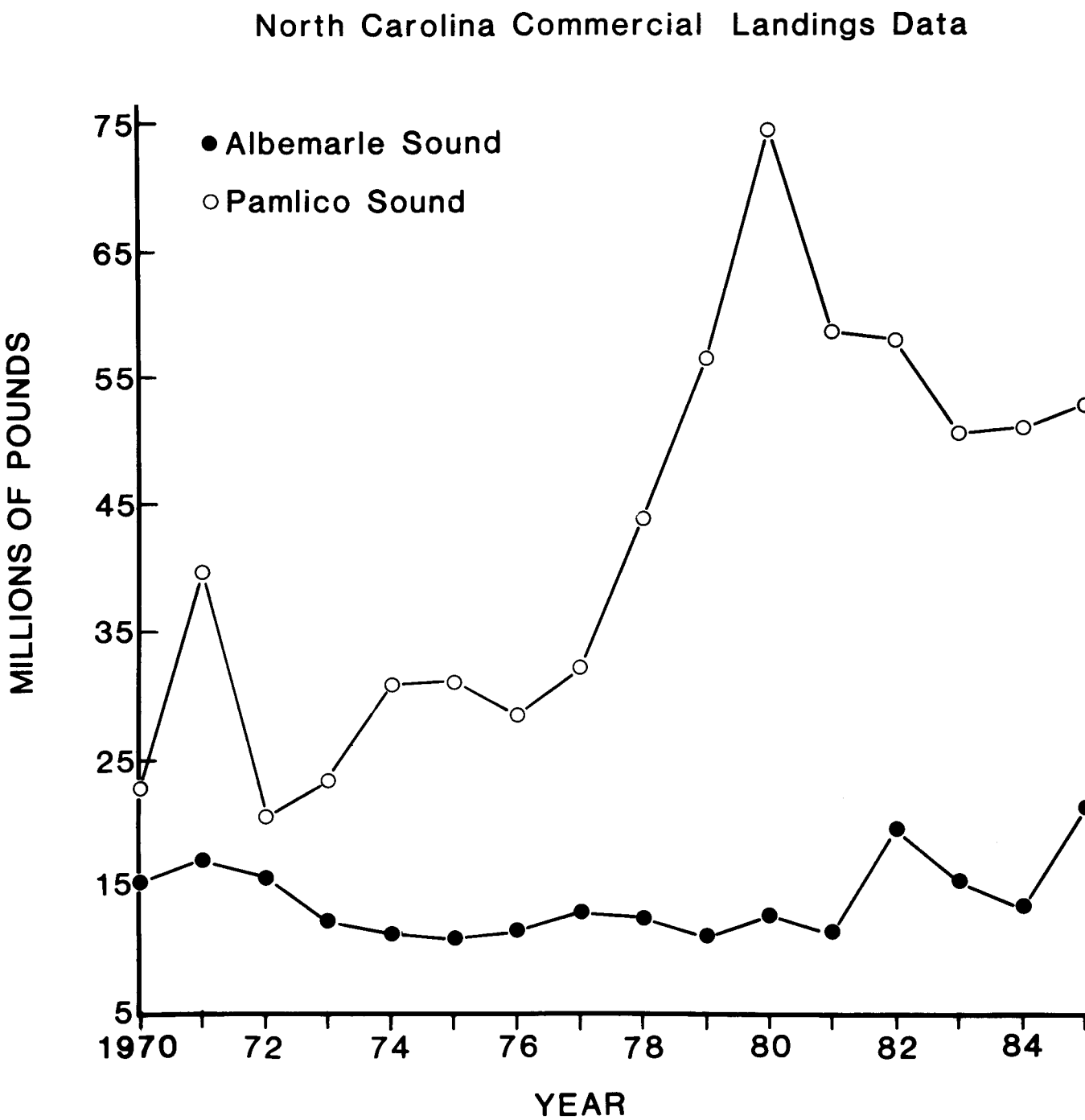
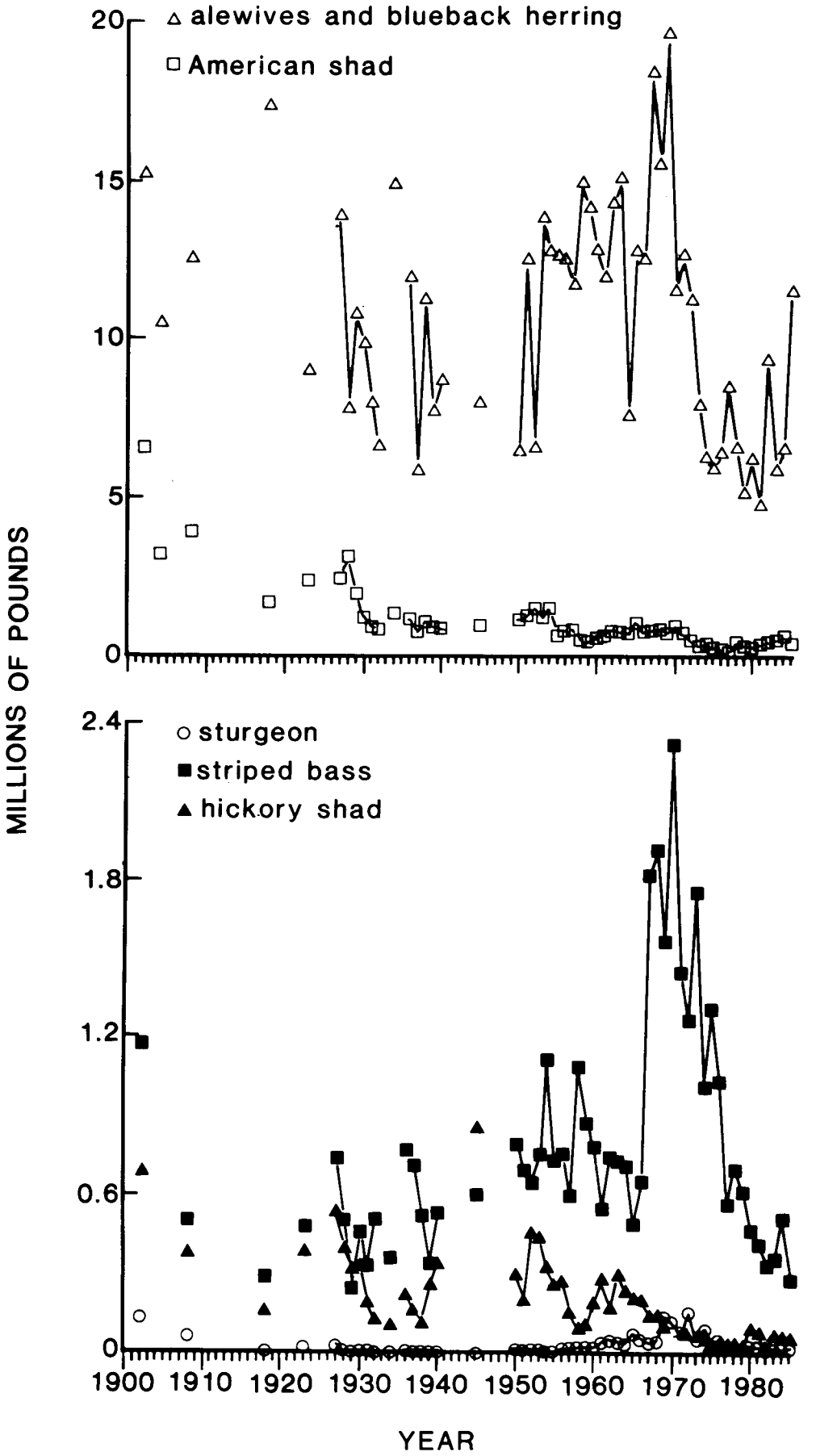

North Carolina Commercial Landings Data
Albemarle Sound
Pamlico Sound
MILLIONS OF POUNDS
75
65
55
45
35
25
15
5
1970
72
74
76
78
80
82
84
YEAR

Figure 5. North Carolina commercial fishery landings of anadromous species, 1904-1985 (Chestnut and Davis 1975; N.C. Div. Mar. Fish., unpubl. data).

N.C. Commercial Landings of Anadromous Fishes



(Street and Johnson 1982). Other species fished commercially which vary in importance are blue crab, American eel, spot, Atlantic croaker, and southern flounder (Table 3). These are caught mostly from late spring through fall. The commercial catch from this area is currently about 3-5% of the state total (Copeland et al. 1983) and has varied between 2-12% over the last 20 years.

Recreational fishermen in this area usually seek striped bass, white perch, yellow perch, spot, Atlantic croaker, southern flounder, and in the upper reaches, largemouth bass. Although largemouth bass and striped bass were the most sought after species in the Albemarle Sound area, white perch numerically dominated the recreational fishery (Mullis and Guier 1981). Between 1977-1980 most recreational fishing effort was in Currituck Sound and Chowan River with most effort occurring in the summer months of June and July. Mullis and Guier (1981) pointed out that nearly all recreational fish catches declined during their study. Hassler et al. (1981) and Hassler and Taylor (1984) documented a steady decline in the area's recreational catch per unit effort of striped bass.

The Pamlico-Core Sound area and tributaries are the major inshore fishery producing areas in North Carolina (Table 2; Figure 4). In quantity of catch for inshore fisheries of the United States East and Gulf coasts, this area is surpassed only by Chesapeake Bay, where the landings are approximately twice that of the Pamlico-Albemarle complex (Natl. Mar. Fish. Serv., unpubl. data). However,

catch diversity in North Carolina is greater than in any other Atlantic or Gulf of Mexico coastal state. From April through November, the long haul seine fishery harvests mainly Atlantic croaker, spot, weakfish, Atlantic menhaden, and flounders (DeVries 1980). Larger catches and larger individuals of Atlantic croaker and weakfish occur north of Bluff Shoal, while to the south, especially in Core Sound, flounders and spot predominate in the catches. Penaeid shrimps are trawled throughout the area: brown shrimp during summer - fall, pink shrimp during spring and fall, and white shrimp (depending on year class strength) during late fall - early winter. Pound net fishing for flounder (mainly southern flounder) is a fall activity in the major rivers and throughout Core Sound (DeVries 1981). Southern flounder are also a major component of the winter and spring "crab trawl" fishery that operates in lower Pamlico and Neuse rivers and western Pamlico Sound. Pound nets are also used during summer in eastern Pamlico Sound for drums. Blue crabs are fished by trawl during fall - spring (cool weather) and by crab pot during late spring - fall (warm weather). There is some winter pot fishing for crabs in Core Sound and southeastern Pamlico Sound. Major species contributions are summarized in Table 3. Table 4 compares values of area commercial fisheries and complements Figure 4.

Recreational fishing is quite diverse throughout the Pamlico-Core Sound area because of its large size and great variety of the physicochemical environments and habitats.

Table 4. Total ex-vessel commercial fishery values (millions of dollars) by area (N.C. Div. Mar. Fish., unpubl. data). All values exclude industrial fish landings. See Figure 4 for comparable weight data. The Pamlico Sound area includes Core, Croatan and Roanoke sounds and the Albemarle Sound area includes Currituck Sound. Tributaries are included.

Year	Pamlico Sound area	Albemarle Sound area
1968	4.2	0.8
1969	6.1	1.0
1970	3.6	0.7
1971	4.9	0.8
1972	4.2	0.9
1973	5.6	0.9
1974	6.6	1.1
1975	6.6	1.1
1976	10.0	1.6
1977	10.5	1.5
1978	10.3	1.9
1979	16.1	1.8
1980	26.8	1.9
1981	18.9	1.9
1982	24.7	3.1
1983	22.6	3.0
1984	19.1	2.5
1985	31.1	3.2
18 year mean	12.9	1.7
Overall N.C. 18 year mean	30.8	

Major species caught are Atlantic croaker, weakfish, spotted seatrout, flounders, bluefish, spot and brown shrimp (U.S. Dep. Commer. 1984, 1985a, b). Pinfish are commonly caught, occasionally used for food and often used for bait; juvenile Atlantic menhaden and shrimp also are popular recreational bait. Recreational activities are generally from late spring through late fall, with the peak in summer and fall. Hayne (1968) found that overall North Carolina recreational fishermen fished mostly from the beach surf area, followed in order by ocean piers, boats, shorelines, jetties, and sound piers. He reported that the most often caught fishes were (in decreasing abundance): spot, southern kingfish, bluefish, black sea bass, king mackerel, and 18 other species. This ranking emphasizes ocean caught fishes as expected from the above site ranking. Although data are lacking, recreational species and site rankings may have changed since Hayne's (1968) report. The southern kingfish, black sea bass, and king mackerel are rarely caught recreationally in estuaries. Atlantic croaker and flounders replace them in estuarine recreational importance after spot.

One major difference between the commercial fisheries of Albemarle Sound and the Pamlico-Core Sound area is that annual invertebrates (species such as blue crab and penaeid shrimp which provide only one year class to a fishery) dominate the landings in Pamlico-Core Sound. In addition, the fishes landed from this area are generally shorter-lived than those from Albemarle Sound. Atlantic croaker, spot,

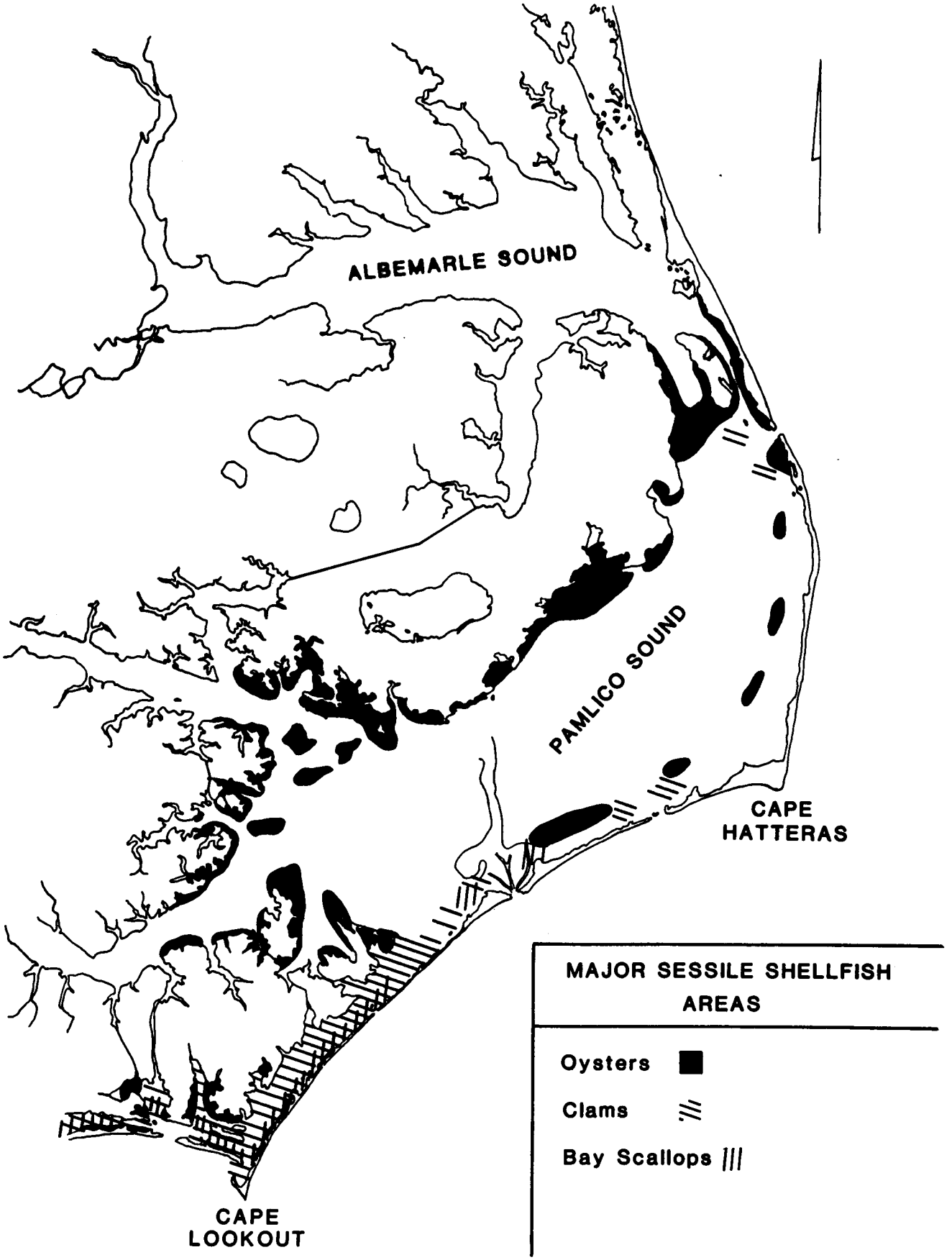
and Atlantic menhaden, which form the bulk of the long haul seine fishery in Pamlico Sound, are usually less than 2-3 years old (Ross 1982). In contrast, alewife and blueback herring are longer-lived and ages 3-6 years are dominant in Albemarle fisheries (Johnson et al. 1977; Winslow and Sanderlin 1983), and the age groups of 5-6 years are most common for white perch (Keefe and Harriss 1981). Since annual and short-lived species often exhibit extreme population size variations, fishery production from the Pamlico-Core Sound areas may be expected to vary (seen to some extent in Figure 4) and be less sensitive to overfishing than fisheries in Albemarle Sound.

Catches of many species have declined despite the overall trend of increasing landings in the state. Landings of anadromous species, particularly American shad (Walburg and Nichols 1967; Sholar 1977), hickory shad (Marshall 1977), and striped bass (Hassler et al. 1981; Hassler and Taylor 1984), have decreased (Figure 5). Explanations for the declines range from overfishing to reduced egg viability and survivability of young of the year (YOY). Only predation on striped bass YOY has been ruled out as a significant cause of decline in that species (Rulifson 1984). However, the decline in striped bass landings between 1984 and 1985 were due, in part, to stricter restrictions imposed on the fishery by the North Carolina Marine Fisheries Commission as part of an interstate management plan of the Atlantic States Marine Fisheries Commission (ASMFC 1981).

MAJOR SESSILE INVERTEBRATES

Major commercially and recreationally important shellfish of North Carolina's estuaries are American oysters, hard clams, and bay scallops. Although these animals produce pelagic larvae, they tend to settle successfully only in certain areas (Figure 6). These shellfish generally occupy medium to high salinity regions of the estuary. Bay scallops are mostly restricted to Zostera marina (eel grass) beds, which are abundant in Bogue, Back, and Core sounds (Figure 6). Carraway and Priddy's (1981) estimate of 78.7 km^2 (19,458 acres) of grass beds in these areas also can be used as an estimate of bay scallop producing area. Even though grass beds are common to the north behind the Outer Banks, substantial numbers of scallops do not occur north of Ocracoke Inlet (M. Marshall, N.C. Div. Mar. Fish., pers. commun.). A similar distribution pattern also characterizes hard clams, except that these shellfish occur in deeper water areas in addition to shoals and shallow eel grass beds (Figure 6). Oysters are more broadly distributed (Figure 6), but still are not found in oligohaline waters or very deep waters (Munden 1975; M. Marshall, N.C. Div. Mar. Fish., pers. commun.). Over 239 km^2 (59,000 acres) of oyster bottoms have been estimated for the Pamlico Sound area (including northern Core sound, Roanoke and Croatan sounds, and lower Neuse River) (N.C. Div. Mar. Fish., unpubl. data). All of the above shellfish, except bay scallops, exhibit prolonged spawning seasons that last throughout the summer and,

Figure 6. Major sessile shellfish producing areas in the Pamlico-Albemarle area, North Carolina (N.C. Div. Mar. Fish., unpubl. data).


ALBEMARLE SOUND
PAMLICO SOUND
CAPE HATTERAS
CAPE LOOKOUT
MAJOR SESSILE SHELLFISH AREAS
Oysters
Clams
Bay Scallops

sometimes for oysters, into the fall. Bay scallops spawn throughout the fall. Asiatic freshwater clams (Rangia cuneata), which are sometimes harvested for human consumption and for the shells, are common in Albemarle Sound and the upper reaches of most rivers (Copeland et al. 1983, 1984).

Unlike the harvest areas for more mobile organisms, fishing grounds for the sessile shellfish occur in the same areas which also serve for all life history functions (spawning, nurseries, feeding, etc.) except the pelagic larval stage. Oysters and bay scallops are commercially and recreationally harvested mostly by dredges and hand methods from late fall through early spring. Clams are harvested during most of the year in shallow areas by hand methods and seasonally in deeper waters by hydraulic dredge and "kicking" (trawling through propeller wash disturbed areas).

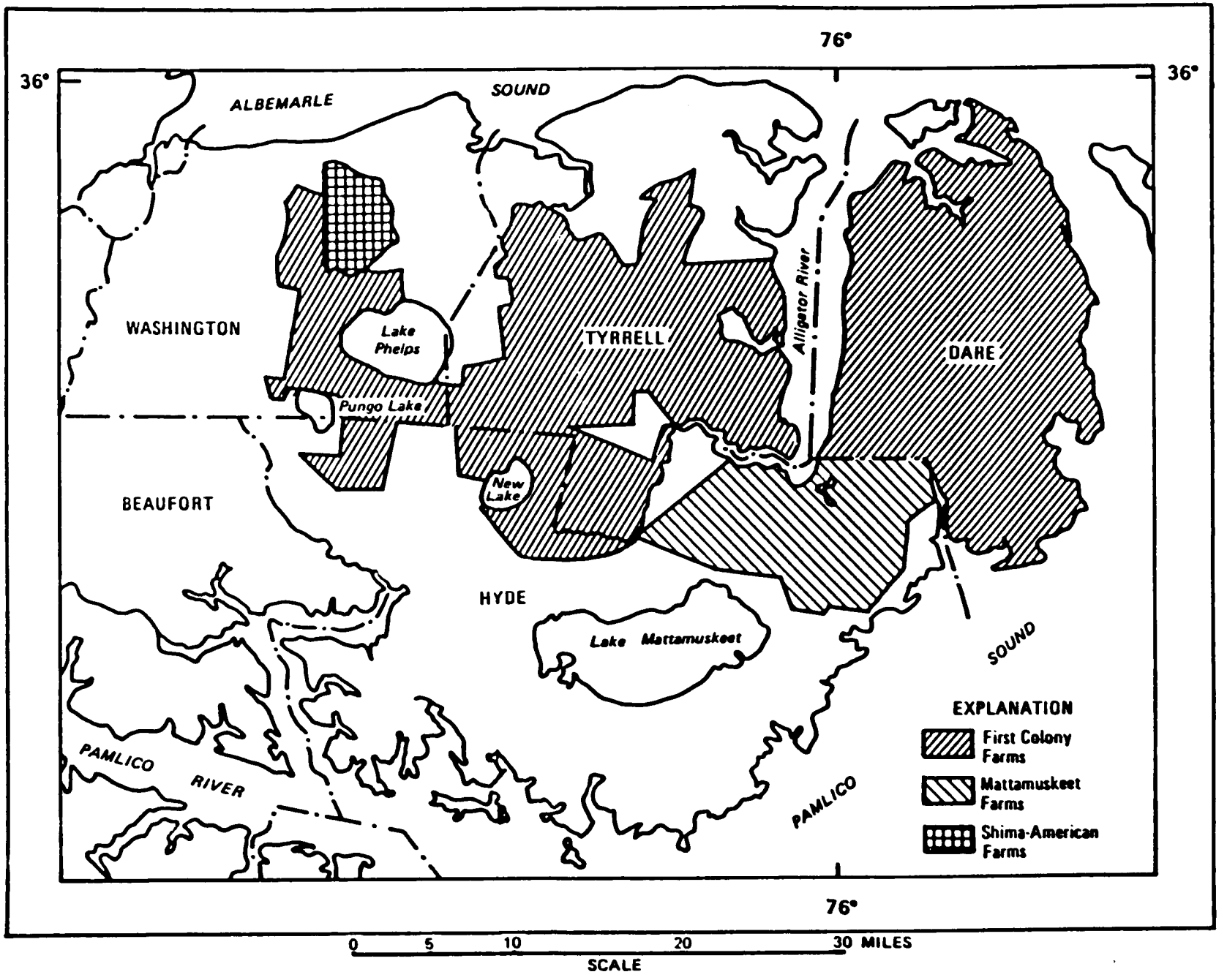
Shellfish production has declined as the number of acres of harvestable bottom have been closed due for health reasons or as these areas become unproductive for other reasons, which may include increased siltation, decreased salinities, degraded water quality, and overfishing. Decisions to open or close North Carolina waters for shellfishing are based on water quality and are independent of whether significant shellfish resources exist in the area. Currently, around 28% of Albemarle Sound, 33% of Neuse River, 41% of Pamlico-Pungo rivers, and 17% of Bay River waters are closed to shellfishing (N.C. Dep. Human Resour., unpubl. data). Although Albemarle Sound and most

of these areas are not high producers of shellfish (except Rangia), these figures indicate a water quality problem probably due to inland pollution. In contrast, less than 2% of Core or Pamlico Sound waters are currently closed to shellfishing. Shellfish production problems in the latter areas are probably not directly related to pollutant loading. Historically, shellfish (oysters) had a broader distribution than at present (Figure 6), and extended farther up the Neuse and Pamlico rivers.

IMPACTS

Changes in land use patterns within the drainage basins of the Pamlico-Albemarle complex have impacted the estuarine area. Currently, the major land uses along the watershed are for agriculture and timbering, the most important of the non-point sources of runoff and nutrient input (Copeland et al. 1983; N.C. Dep. Nat. Resour. Community Dev. 1986b). However, the coastal area is receiving increased pressure for urbanization and for large scale land development. Currently the timber industry controls 44% of the pocosins in North Carolina and nearly 2024 km^2 (500,000 acres) of the pocosins were converted from forestry to large-scale agriculture between 1962 and 1980 (Richardson et al. 1981). Almost half the Pamlico-Albemarle Peninsula is owned by large corporations (Figure 7) (Heath 1975) that use the lands for agriculture or are proposing to reclaim the lands for agriculture after strip mining the peat overlaying the mineral soils. Large-scale farming exists on the

Figure 7. Land owned by large corporate farms in 1974 on the Pamlico-Albemarle Peninsula, NC (from Heath 1975).


76°
36°
36°
ALBEMARLE
SOUND
WASHINGTON
Lake Phelps
Pungo Lake
TYRRELL
Alligator River
DARE
BEAUFORT
New Lake
HYDE
Lake Mattamuskeet
SOUND
PAMLICO
RIVER
PAMLICO
EXPLANATION
First Colony Farms
Mattamuskeet Farms
Shima-American Farms
76°
0 5 10 20 30 MILES
SCALE

southeastern shore of the Neuse River and two strip mines - one for peat and one for phosphate - are located in Pamlico and Beaufort counties, respectively. Significant point sources of pollutants include industrial outfalls, mainly pulp mill effluent and effluent from phosphate mining operations, and municipal sewage treatment facilities (Copeland et al. 1983). Dredging and filling to accommodate navigation and to increase the amount of waterfront property, and the damming of the tributaries for water control also have occurred in the estuarine complex.

The hydrology of the estuary has been altered through channelization and land development within the watershed basin. Due to the low elevation and the high water table in the coastal region of North Carolina, drainage is necessary for the successful development of the lands. This is usually accomplished through a network of main canals with field and feeder ditches ultimately draining into the estuary. Peak runoff is higher and much sooner on developed lands than on undeveloped areas, destabilizing the salinities of the receiving waters. Rapidly fluctuating salinities are stressful to many estuarine organisms (Hochachka 1965; Livingstone et al. 1979) and some species, such as spot and Atlantic croaker, exhibit strong avoidance reactions to fluctuating salinities (Gerry 1981). Nursery area catches of several commercially important species were significantly lower at northwestern Pamlico Sound stations exhibiting the most unstable salinity patterns (Pate and Jones 1981). The effect of increased inflow on the

salinities of the estuarine complex are not clearly documented, but there are records indicating a decrease in salinity in the estuarine system (Sholar 1980). A salt marsh's resiliency is limited and sustained levels of increased runoff may leach sediment salts causing permanent changes in the flora and fauna of the coastal wetlands (Zedler 1983). Such perturbations may decrease the area of nursery habitat for species dependent on brackish waters and allow the limnetic interface to move downstream. Dams on the major tributaries, which have somewhat dampened the seasonality of salinity fluctuations, may have been detrimental to the productivity of the system. The dams are also barriers to the upstream migrations of anadromous and catadromous fishes and may be the cause, at least in part, for the decline in Albemarle Sound landings of American shad (Walburg and Nichols 1967).

Drainage from developed lands has a higher sediment and nutrient load than waters draining undeveloped lands (Kirby-Smith and Barber 1979; Skaggs et al. 1980). High levels of suspended sediment have been demonstrated to reduce the survival of fish eggs and larvae (Auld and Schubel 1978) and interfere with the reproduction of sessile shellfish (Galstoff 1964). Decreased light levels as a result of increased turbidity can significantly impact primary production, decreasing oxygen production (Russell-Hunter 1970). Increased turbidity has also been cited as one possible cause for the near complete disappearance of aquatic macrophytes in the lower Pamlico

River, although low winter temperatures and high salinities in the late 1970's are probable causes, too (Davis and Brinson 1976; M. Brinson, E. Car. Univ., pers. commun.).

Nutrient loading, particularly of nitrogen and phosphorus, in estuarine waters of North Carolina has increased at least one order of magnitude over that of pre-development conditions (Kirby-Smith and Barber 1979) and has been implicated in the eutrophication of coastal waters (Stanley 1985). Nuisance blooms of algae now occur regularly in the Chowan and Neuse rivers whereas prior to 1970 such blooms were rare (Paerl 1982, 1983). Elevated BOD (biological oxygen demand) levels due to increased microbial activity on the suspended particles and on decomposing organic material, such as blue-green algal biomass associated with the nuisance blooms, can lead to oxygen stress in estuarine waters during periods of thermal or salinity stratification (Paerl 1982). Depressed levels of dissolved oxygen may result in the production of toxic hydrogen sulfide gas; both the lack and oxygen and the presence of H_2S may result the deaths of benthos and fish. In addition, the occurrence of the bacterium, Aeromonas hydrophilia, which causes red sore disease in fish, is strongly correlated with the same water quality factors leading to eutrophication (Esch and Hazen 1980). Oligohaline or freshwater fishes such as white perch, striped bass, catfish and American eel, most frequently exhibit the symptoms of such bacterial infections. Recently, ulcerated sores have appeared on Atlantic

menhaden, southern flounder, Atlantic croaker, and several other species utilizing estuarine nursery areas along the Middle and South Atlantic coast. The disease was particularily prevalent in the Pamlico and Neuse rivers in 1984 where infestation, as indicated by the large proportion of dead fish with ulcerative mycosis taken in samples of the fall fish kills, was high (J. Hawkins, N.C. Div. Mar. Fish., pers. commun.). The presumptive causative organism, Aphanomyces sp., has been isolated, but the pathway of its infection and its life history are not understood (Noga and Dykstra 1986). The fungus' occurrence also appears to be correlated with low salinities (J. Hawkins, N.C. Div. Mar. Fish., pers. commun.).

Other pollutants are found in runoff from developed land. Pesticides, herbicides, and organochemicals used in forestry and agriculture and heavy metals released during land development may stress or kill the estuarine organisms. These pollutants may persist in the environment (Eisler 1972) and accumulate through the food chain (Moore and Ramamoorthy 1984; Butler 1966). Coliform bacteria, which are used as indicator organisms for the presence of animal-borne disease, are also more abundant in runoff waters (Skaggs et al. 1980) and are found in high concentrations near municipal sewage and storm outfalls and marinas (N.C. Dep. Human Resour. 1985).

Environmental stress on the Pamlico-Albemarle system probably will increase. North Carolina's population is steadily rising (Figure 8) and, consistent with the national

Figure 8. North Carolina census data 1910-1980 and projected population sizes through 2000 (N.C. Ofc. State Budget and Mngt. 1984, 1985).

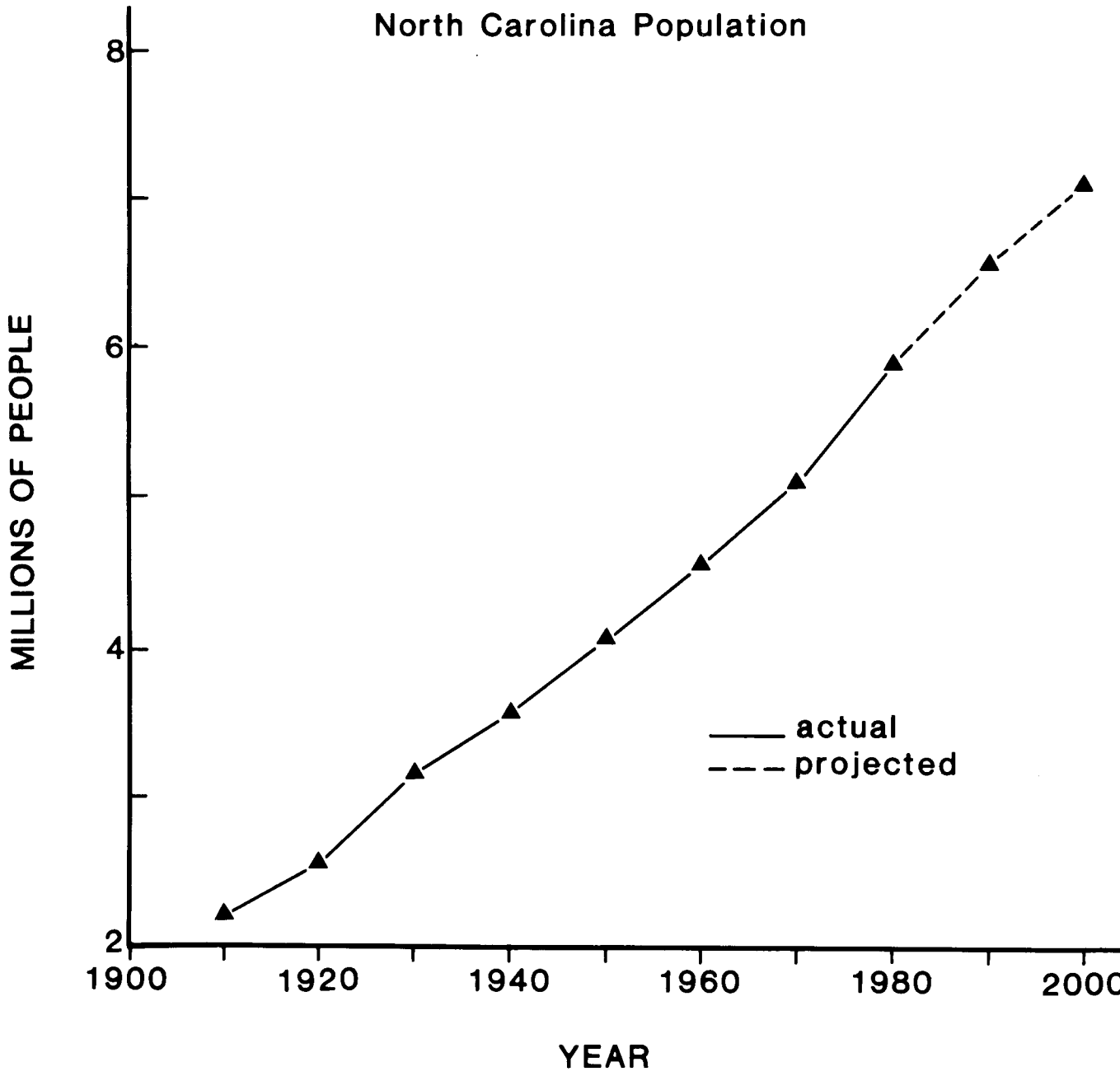
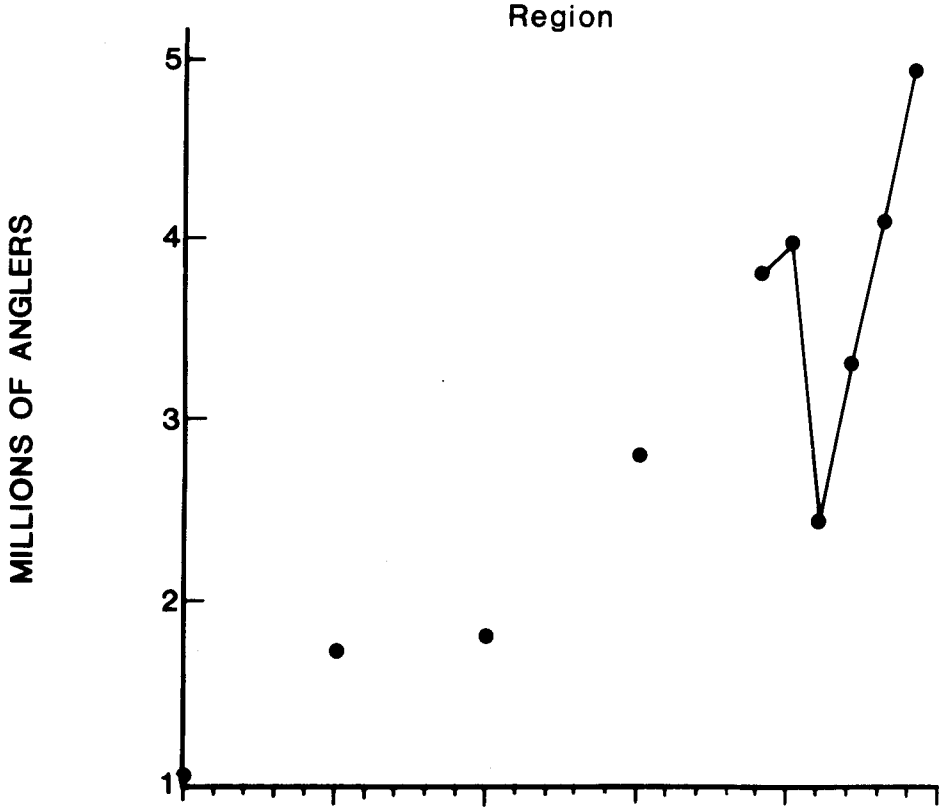
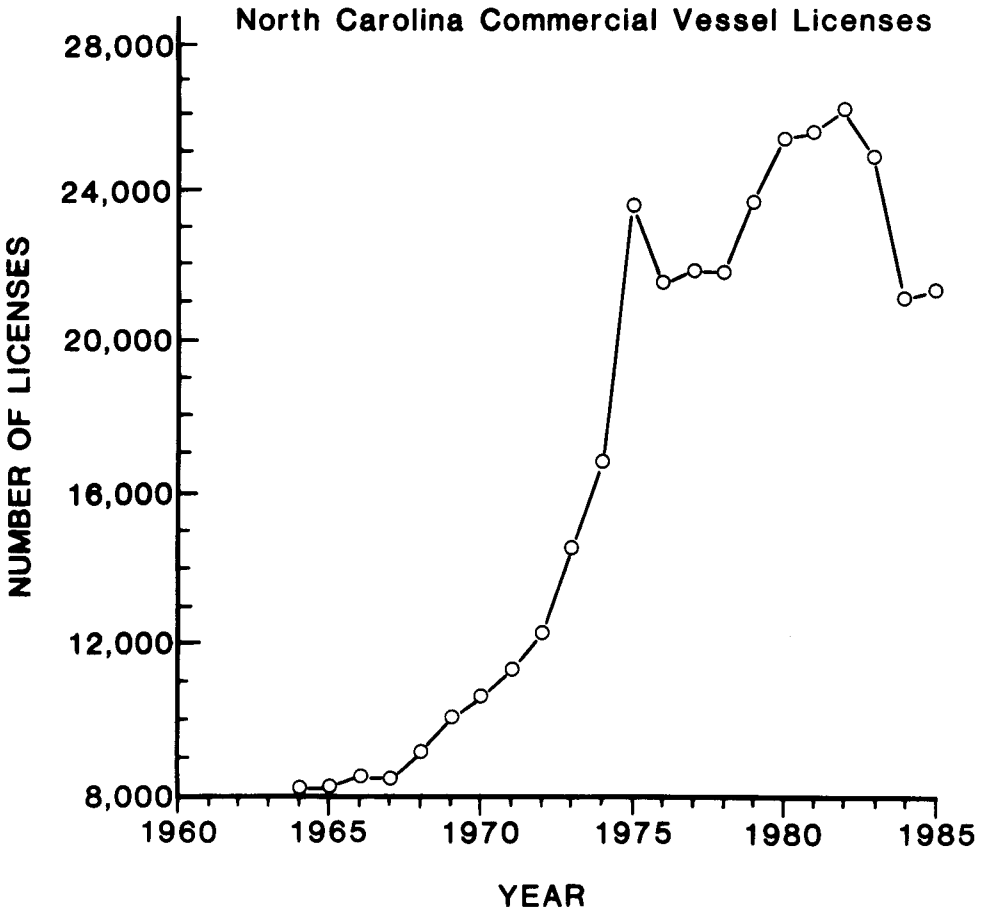

North Carolina Population
MILLIONS OF PEOPLE
8
6
4
2
1900
1920
1940
1960
1980
2000
YEAR
actual
projected

Figure 9. North Carolina commercial vessel licenses sold 1964-1985 (N.C. Div. Mar. Fish., unpubl. data) and number of recreational anglers in the South Atlantic region 1960-1984 (Deuel 1973; U.S. Dep. Inter. 1977; U.S. Dep. Commer. 1984, 1985a, b). Since 1979 recreational participation in North Carolina has accounted for approximately one-third the regional total. The fee structure for the commercial licenses was consistent until 1984 when there was a significant increase in fees (M. J. Roberts, N.C. Div. Mar. Fish., pers. commun.). Vessels licensed for hire, a category added in 1984, are not included in the total.

Recreational Anglers in the South Atlantic Region



North Carolina Commercial Vessel Licenses



trend, will shift towards the coastal regions. The state is expected to experience a 20% growth in population between 1980 and 2000 (N.C. Ofc. State Budget and Mngt. 1984, 1985). Land development with its associated impacts and increased recreational pressure on the coastal waters will parallel the rise in population.

Development in the coastal zone already has escalated. Between 1970 and 1983, the N.C. Division of Coastal Management annually issued approximately 225-250 Coastal Area Management Act major development permits. Since 1984 the rate of issuance for the same class of permits has doubled, reflecting the increase in coastal development concomittant with the general economic recovery nationwide (P. Pate, Div. Coastal Mngt., pers. commun.). One of the results of development, increased sludge produced by publicly owned sewage treatment works in coastal counties, is projected to increase nearly three-fold (Cross et al. 1985).

As the population increases, the recreational and commercial pressures on the fishery resources will increase. The number of commercial fishing vessel licenses sold have more than doubled since the early 1960's (Figure 9) (N.C. Div. Mar. Fish., unpubl. data). The number of recreational anglers in the South Atlantic region has increased nearly five-fold since the 1970 survey (Deuel 1973; U.S. Dep. Inter. 1977; U.S. Dep. Commer. 1984, 1985a, b), and since 1979, about one-third of all recreational fishing activity in the region occurred in North Carolina, trailing only

Florida. Recreational participation in North Carolina is split approximately 70% non-coastal and out-of-state anglers and 30% coastal residents (U.S. Dep. Commer. 1984, 1985a, b).

Because the watershed of the Pamlico-Albemarle estuarine system is large, extending into the Piedmont west of Raleigh and north to the Allegheny foothills of Virginia (70% of the Albemarle Sound watershed is within Virginia (Copeland et al. 1983)), analysis and mitigation of impacts will be complex. There are many potential conflicts between land (e.g. agriculture, forestry, municipalities, and industry) and water (recreational and commercial fisheries, recreation, and tourism) user groups. Thus, management plans developed for this estuarine complex must encompass the entire watershed, represent all user groups, and of necessity involve the jurisdictional interactions of numerous and diverse agencies of the two states and the Federal government.

ACKNOWLEDGMENTS

The assistance of R. Clayton, P. Fowler, J. Hawkins, H. Johnson, M. Marshall, T. Sholar, and K. West is gratefully acknowledged. We also thank H. Gordy for the illustrations and D. Ahrenholz, D. Colby, F. Cross, M. Currin, J. Hawkins, D. Hoss, C. Manooch, M. Marshall, J. Merriner, J. Miller, H. Paerl, M. Street, and D. Vaughan for reviewing this manuscript.

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